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VOL. I. JULY–AUGUST, 1907. No. 4.

Variation in the Leading Features of the Tide in Different Regions	*W. Bell Dawson*	213
Errors of Transit Observations	*R. M. Stewart*	228
The Spectroscopic Binary α Draconis	*W. E. Harper*	237
Work at the Lick Observatory and Improvements in its Equipment	*C. A. Chant*	246
Notes from the Dominion Observatory		264
An Appeal from the Astronomical Society of the Pacific		268
Astronomical Notes		269
Summary of Weather of Canada for July and August		270

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Journal of the Royal Astronomical Society of Canada, 1907.

THE JOURNAL
OF THE
ROYAL ASTRONOMICAL SOCIETY
OF CANADA

VOL. I. JULY-AUGUST, 1907. No. 4.

VARIATION IN THE LEADING FEATURES OF THE TIDE IN DIFFERENT REGIONS.

BY W. BELL DAWSON.

THE tides of the eastern coasts of Canada are very varied in character and thus exemplify several different types. They vary in range from the largest tides of the world, in the Bay of Fundy, to a tide which is almost inappreciable in the middle of the Gulf of St. Lawrence. In this they contrast with the tides on the Atlantic coast of the United States, which have a remarkably uniform character from Cape Cod to Florida. On our Pacific coast, the tide shows other features which supplement those of the Atlantic tides.

The object of this paper is to draw attention to the manner in which the tide is found to have some leading feature in each region, which is evidently dominated by some one element in the moon's movements; such as its declination or its distance or the period of its phases. As all our east coast tides, to their furthest limit in the River St. Lawrence, are propagated from the tide of the open Atlantic, it is evident that the influence of some one lunar factor must become more and more pronounced during the progress of the tide, until it stands out as the dominant feature. In this way, the declination effect may develop in one region, or the distance effect in another, until other features in the tide become relatively unimportant.

This has become clear in carrying out the general method adopted for the Survey of Tides and Currents. A limited number of principal tidal stations were established at strategic points, from which the tides at a large number of harbours and ports of secondary importance are deduced by means of "tidal differences." These are differences in time, and ratios for height, by which the tides at other localities can be computed from the tide tables prepared for the principal stations, which are based upon harmonic analysis.

If the attempt is made to deduce the tide at some harbour from a principal station or port of reference at which the tide is of a different type, large errors may result. For instance, tables are published in which the tides of the whole world are referred to Brest in France, by constant differences of time ; but the result for many places is quite unreliable. In the United States tide tables, some of our St. Lawrence and Gulf ports used to be referred to distant tidal stations, which resulted in errors of 1½ hours to 2 hours, early or late, in the time of the tide. As an example, the error in the tide at Pictou, within the Gulf, if calculated from Halifax by the use of a constant difference of time, is shown in the following table.

Date	Time of High Water		Actual Difference	Error with Constant Difference	Remarks
	Pictou	Halifax			
	h. m.	h. m.	h. m.	h. m.	
1896, July 8	7 10	6 15	0 55	− 1 24	Moon's declination maximum north
" " 8	21 11	18 02	3 09	+0 50	
" " 9	8 02	6 50	1 12	− 1 07	
" " 9	22 07	18 55	3 12	+0 53	
" " 10	9 00	7 50	1 10	− 1 09	
" " 10	23 15	19 30	3 45	+1 26	New moon
" " 11	9 45	8 35	1 10	− 1 09	
" " 11	23 57	20 22	3 35	+1 16	
" " 12	10 35	9 15	1 20	− 0 59	

It must not be assumed that it is the distance of a port of reference which necessarily interferes with accuracy in deducing the tide from it by means of a constant difference. It may prove quite possible to apply constants to a port of reference in

another part of the world, provided that the type of the tide is really the same. An attempt on these lines was made for the tides along the St. Lawrence river, in the United States tide tables of ten years ago, before data were secured by this Survey. The tides above Quebec as far as Lake St. Peter were referred to various ports in Burma, Germany, Newfoundland, and Florida; but the results thus obtained were quite unsatisfactory. These ports appeared to be chosen as having the same range as the successive points along the St. Lawrence, which were referred to them; but the mere fact that the range of the tide is the same at two distant places, affords no guarantee that the tide is of the same type.

If a region of limited extent is taken, it is usually possible to refer all its tides to a principal station in the region by means of time-differences and ratios for height which are constant, and thus to secure good results. But if it should prove that the type of the tide is undergoing change in its progress through the region, the time-differences with the principal station will no longer be constant. It is usually found that the variation in the difference takes place in the period of one or possibly two of the various lunar months known to astronomers. More usually, the variation which corresponds with some one element in the moon's movement is so strongly marked that all other variations can be ignored in practical calculations.

On the Pacific coast, the solar influence is so large, relatively to the lunar, that the chief variation in the tidal difference is found to be an annual one. When this is allowed for, any variations in the course of the month are relatively insignificant.

From this variation in tidal differences, it appears that when some leading feature begins to manifest itself in the tide, this may continue to develop with its progress through the region in question, till it becomes the dominant characteristic. We will not venture to offer an explanation for these variations and changes in the features of the tide, but will only give examples of them, as they are so remarkably illustrated by our Canadian

tides. We will thus hope to make the facts clear; and will leave the explanation to astronomers with competence to deal with it.

The regions may be classified with reference to the lunar element which is found to dominate each, in the period of one of the various lunar months. The lengths of the months which have the most importance from a tidal point of view, are given below in tide-intervals or half lunar days, which is the true tidal unit.

Synodic month of the moon's phases	= 57·06	tide intervals
Anomalistic month; moon's distance	= 53·24	" "
Tropical or declination-month	= 52·79	" "

These values are necessary as a basis in making an analysis of tidal differences in the period of any of these lunar months.

Anomalistic month.—In all parts of the world, the tides are found to accord with the varying movements and distances of the moon and the sun. In the North Atlantic, where they were first studied, it happens that they are chiefly influenced by the moon's phases. It was thus supposed that the primary characteristic of all tides was a marked alternation in height from springs to neaps in the period of the synodic month.

In the Bay of Fundy, however, it is a noteworthy feature of the tide, that the variation in range from Perigee to Apogee is greater than the difference in range at mean springs and mean neaps. This shows the dominating influence of the moon's distance in that region, in the period of the anomalistic month. The strong tidal currents in the Bay of Fundy have also a variation in strength which follows the same law.

The data given below for St. John are from the record of the registering tide gauge there. The springs and neaps selected are in the months of August and September, when the Perigee and Apogee coincided with the full and change of the moon; and the intermediate neaps were closely at the moon's mean distance. The range given is the mean for two consecutive high waters and low waters, as the diurnal inequality is thus eliminated. The data for Cumberland Basin are from the day tides only, taken in 1870 by the Engineers of the proposed Baie Verte canal. The

months selected are October and November, when the above coincidence occurred in that year.

Description of Tide	St. John, N.B.		Cumberland Basin	
	Range in feet	Difference	Range in feet	Difference
At Perigee. Range at Spring Tides	27·10	6·75	48·20	12·65
At Apogee. Range at Spring Tides	20·35		35·55	
Spring range. Mean of the above	23·72	6·29	41·87	12·12
Neap range, at Moon's mean distance	17·43		29·75	

The tidal differences throughout the Bay of Fundy are remarkably constant, however. The time-difference between Yarmouth and St. John, as obtained from two years of simultaneous observation, shows no appreciable variation in the course of the month or during the year. This indicates that the anomalistic feature is already fully developed at Yarmouth, where the range is only 16 feet ; although the range itself continues to increase to 50 feet at the head of the bay.

Synodic month.—In dealing with the St. Lawrence tides, the endeavour was made to extend the region referred to Quebec to include the whole of the estuary of the St. Lawrence, and thus to save a reduction by harmonic analysis at an additional tidal station. It has proved better, however, to raise Father Point, in the middle of the estuary, to the rank of a principal station ; but the earlier endeavour resulted in an elaborate comparison of the tides at Father Point and Quebec, which are 190 miles apart in one of the largest tidal estuaries in the world.

The crest of high water takes some 4½ hours to run up the estuary from Father Point to Quebec ; and low water still longer. Simultaneous observations at the two places during two complete years, summer and winter, afforded 1250 time-differences for high water, and 1280 for low water.

On making a close examination of the whole series of differences, it appeared that in the case of low water a double variation in the difference of time occurred ; firstly, in the period of the synodic month with the moon's phases, and secondly, in the period of the anomalistic month with the moon's

distance. The amounts of these variations in the difference were ascertained by four series of analyses, in the periods of each of these months, and for high and low water, respectively.

In the case of high water, the variation with the moon's phases is not great, and the variation with the moon's distance is only 2 minutes more or less than the mean value, and may be neglected.

In the case of low water, the variation in the difference is larger, and the outcome of the analyses which were made, is given in Table A. appended, which was used in former years for the calculation of tide tables for Father Point.

The following synopsis shows the proportion of the variation in the difference for high water and for low water, which can be reduced to law, and which is allowed for by the use of this table. The greatest outstanding error which can occur at any time is *half* of the remainder unaccounted for, which includes weather disturbance, and the diurnal inequality occurring for a few days at the moon's maximum declination.

Father Point and Quebec	High Water	Low Water
Variation in the difference in the synodic month	5 m.	32 m.
" " anomalistic month	4 m.	25 m.
Diurnal inequality in the difference	14 m.	14 m.
Remainder unaccounted for (weather, &c.)	34 m.	11 m.
Total variation in the difference (average amount)	57 m.	82 m.

Tropical or Declination-month.—The use of the term tropical may be admissible, as it is defined by the return of the moon to the same longitude ; and the period of the moon's variation in declination is the same in the long run, because the point of intersection of the moon's path with the equator can only oscillate a few degrees on each side of the equinoctial point. This use of the term has the advantage of corresponding with the tropical year, which is also primarily the period of the sun's variation in declination. This declination-month is a period of the first importance from a tidal standpoint.

The element in the tide which is under the influence of declination, is the diurnal inequality. When the moon's

declination is high, an alternation in the time-interval and the height at successive tides, which accords with the moon's upper and lower transits, is almost everywhere appreciable ; and in some regions this becomes so pronounced as to become the leading feature in the tide.

Northumberland strait affords a noteworthy example of a region dominated by the declination of the moon. At Charlottetown, where the range amounts to ten feet, the difference between the two tides of the 24 hours is greater than the difference between springs and neaps. A similar inequality affects the current in the strait. The difference of time between the turn of the current and the local tide is large ; as the turn may take place within limiting periods of two hours relatively to the time of high water or low water ; and the variation follows the change in the moon's declination. This is very confusing to the mariner, as the turn of the current is out of accord with the moon's phases, and has thus no fixed relation to the spring and neap tides. The greatest apparent irregularity is when the moon's declination is at its maximum ; and this occurs sometimes at the spring tides and sometimes at the neaps. The ordinary navigator takes refuge in the conclusion that the currents are chiefly influenced by the wind. But the observations show that the apparent irregularities can be reduced to definite laws, which, although complex, are strictly astronomical in character.

It is evident that this feature in the tide develops during its progress. In the open Atlantic, as represented by the tide at Halifax, the diurnal inequality although appreciable is by no means noteworthy. But after entering the Gulf, as the tide proceeds westward towards Northumberland strait, the diurnal inequality becomes more pronounced ; and it is further accentuated as the tide passes along the strait. It has therefore been found advisable to take Pictou as a secondary port of reference in the middle of the strait itself ; as the inequality in the tide in the two directions can thus be better distributed.

Tide tables for St. Paul island in Cabot strait, the main entrance to the Gulf from the Atlantic, are calculated from the tidal constants resulting from harmonic analysis ; and to obtain data for Pictou, simultaneous observations were taken at the two places during four summer seasons, in 1896, 1897, 1901 and 1903. From these it was found that two series of variable differences in the time of the tide were required ; one for high water and the other for low water. The differences vary in accordance with the declination of the moon, and alternate with its upper and lower transits. It is also found necessary to allow for the variation in the range of the moon's declination in the 19-year cycle, by a modification in the series of differences used, according to the position of the year in the cycle. The table of variable differences which is used for a year when the range in declination is greatest, is appended as Table B.

It is very evident from the result of this investigation, that the declination element increases in the tide as it progresses from St. Paul island to Pictou. It becomes so dominant a feature that all variation in other lunar periods is relatively negligeable in calculating the tides. It also continues to increase as the tide proceeds from Pictou to Charlottetown ; as the difference in time between the two places shows a further variation when the moon is near its maximum declination, north or south.

Why it should be that this declinational feature in the tide develops in Northumberland strait, while the lunar distance element or the anomalistic feature develops on the other side of Nova Scotia in the Bay of Fundy, we do not undertake to explain. A similar development of the declinational feature is also found in Belle Isle strait in both tide and current.

One curious result of a difference in the type of the tide in two neighboring regions, is the effect upon the current in a strait which connects two such regions. The Gut of Canso affords an example of this ; as the irregularity of its currents can only be attributed to the difference in the character of the tide itself, at the two ends of the Gut. The tide in the region of Northumberland strait at its northern end, shows a marked diurnal

inequality, which accords with the declination of the moon ; and as the declination-month is overrun by the period of the moon's phases, this diurnal inequality characterises sometimes the spring tides and sometimes the neaps. While these changes recur periodically at the northern end of the Gut, at the southern end the Atlantic tide maintains the usual variation in height from springs to neaps with great regularity. As the current through the Gut depends on tides which are so different in character at its two ends, it necessarily shows great complexity. Before this explanation was found by the investigation of the tides themselves, it was supposed that the currents were chiefly governed by the wind.

Reversal of the diurnal inequality.—Another interesting feature in the tides of the Gulf of St. Lawrence, is the reversal of the diurnal inequality between the entrance at Cabot strait and the opposite shore to the westward. We may designate as the open gulf coast, the northern part of the coast of New Brunswick and the north coast of Prince Edward island. The tides on these coasts can be referred to St. Paul island, provided that the difference in time is taken as earlier, or for the preceeding tide. Otherwise, the difference in the time of the tide varies so widely as to be practically valueless for purposes of computation. But with the above proviso, a constant difference in time is applicable.

These various examples which illustrate the dominant influence of some one element in the moon's motion in different regions, are also interesting in showing how unwise it is to theorize in carrying out tidal investigations, as the characteristics of each region must be ascertained by direct observation.

Character of the Pacific tide.—The tide of the Pacific can best be described as a declination-tide. Its leading feature is a pronounced diurnal inequality in time and height, which accords with the declination of the moon ; and it is also subject to an annual variation with the change in the declination of the sun. As the solar influence is unusually large in the Pacific the annual variation is the more accentuated.

When the moon is farthest north or south of the equator, the inequality between the two tides of the day is greatest ; and the long and short runs of the current occur. The extreme tides of the year necessarily occur at the nearest point to the solstices at which the moon reaches its maximum declination. On the other hand, the tides become equal when both the sun and moon are on the equator ; or when they are on opposite sides of the equator at distances north and south which are proportional to their respective effects.

The spring and neap tides are thus reduced to a secondary feature which is usually obscured by the stronger characteristics of the tide. The Establishment, which is so well marked in the Atlantic, is here almost illusory ; unless it is strictly reduced to equinoctial and equatorial conditions, in accordance with the definition used in France. It may still be convenient to speak of spring and neap tides, if they are understood to mean the two maxima and the two minima in range or in level which always occur in the period of the lunar month ; although as regards time of occurrence, they may be several days before or after the full or new moon, as these extremes are so largely due to the diurnal inequality.

A tide of this character is apt to be termed irregular by the mariner ; as the tropical or declination-month which is its governing period is less familiar and less noticeable than the synodic month of the moon's phases. It is evident, however, that this tide is perfectly astronomical ; and its analysis and prediction are just as definite as for any other type of tide.

We need not enter upon a description of the various types of tide met with on the Pacific coast, as it will suffice to say that for tidal purposes it is necessary to divide it into three or four regions, with a port of reference in each. For if the attempt is made to compute our British Columbia tides from tidal stations in the United States or Alaska, to the north or south, the resulting errors may exceed one or two hours in time.

Even in the extent of each region, there is still a variation in the tidal difference to allow for. The diurnal inequality can

best be dealt with by classifying the tides, and computing tidal differences separately for the higher high waters, the lower low waters, and the half tides, as those of intermediate range are termed. The differences are then found to be constant throughout a fairly extended region. But when comparisons between two places are obtained for a complete year, a marked annual variation comes to light.

It is thus best, when possible, to base the tidal difference upon a comparison for four months at the four quarters of the year. If these values are not sufficiently constant to give a satisfactory average, then a series of differences must be obtained for each month of the year.

On the open coast of the Pacific, a distinct annual variation has been found in the tidal difference between Port Simpson and Sitka in Alaska. Their latitudes are 54½° and 57° N. The variation in the time-difference for high water, is from $1^h\ 10^m$ at the summer solstice to 51^m at the winter solstice.

In the Strait of Georgia, an annual variation is also distinct, although the time of the tide is nearly simultaneous throughout the strait. The principal station for that region is at Sand Heads, off the mouth of the Fraser River in the middle of the open strait.

Time of Tide in Baynes Sound, compared with Sand Heads. (Monthly Averages.)

	Dec.	Jan.	Feb.	Mar.	Apr.	May
	mins.	mins.	mins.	mins.	mins.	mins.
Difference for H. W.	+3	−1	0	+6	+8	+13
Difference for L. W.	−2	−2	−1	0	0	+6

The following table shows the variation in the time of slack water in Active Pass when compared with the tide at Sand Heads. The amount of this variation is remarkable, as the two places are almost opposite on the two sides of the strait, and only 14 miles distant from each other.

Active Pass	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.
H. W. Slack	0:50	0:50	0:56	1:06	1:18	1:28	1:34	1:34	1:28	1:18	1:06	0:56
	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
Variation from mean	−22	−22	−16	−06	+06	+16	+22	+22	+16	+06	−06	−16

This variation in the course of the year is presumably in accord with the change in the declination of the sun, as this would correspond with the strongly marked effect which declination seems always to have upon the Pacific tides. It is not at all comparable to the variation in a river tide with the season of the year, due to change in the stage of the water, such as occurs in the St. Lawrence above Quebec, where allowance for the month of the year is required in the calculations.

It is quite possible that the annual variation is accentuated by the high latitude, where the direction of the attractive forces in summer is so different from their winter direction, when they become nearly horizontal at the upper or lower transit of the sun and moon. The study of the tides near the Arctic circle might therefore throw an important light on the subject of annual variation ; but as yet the data in those regions is very meagre.

Concluding remarks.—It may not be possible to explain satisfactorily the reason for the development of the different types of tide referred to, until our general tidal data are more complete. But the discussion of the subject may prove of value in its bearing on the study of the tides of the world in general. For it may never be practicable to obtain adequate tidal data for each harbour of the world independently, for which tide tables are required.

The most practical method will no doubt prove to be the classification of the tides into types ; and anything that tends to explain or distinguish these types is of value. A large saving in the work can also be effected by extending the region which can be referred to each principal tidal station, as a port of reference. This can be done by the use of variable tidal differences, as employed by this Survey, which the examples given may serve to illustrate. It will thus be possible to reduce to their least amount the labour and difficulty of securing sufficient tidal record for harmonic analysis ; as the record to serve this purpose, must be continuous day and night throughout the year, and entirely free from interruption.

This variation in the leading features of the tide also shows the importance of placing the principal stations at strategic points where the true type for the region can be secured. From this point of view, many of the important harbours of the world are very unsuitably situated to serve as ports of reference; as they are at the mouths of rivers or in estuaries where disturbing local conditions are most felt. Some small island or isolated lighthouse, well situated as a strategic point, may serve better as a principal tidal station from which to calculate the tides for several important harbours in its region.

The change in the features of the tide, with its progress, points also to the advantage of a tidal station situated as centrally as possible in each region to minimize any variation in the two directions. The extent of the region that can be referred to the station must then be ascertained by observation and investigation, in accordance with the astronomical features which may there happen to be predominant; and this will indicate the type of variable difference best adapted to extend the region as far as practicable. This will also enable the undue multiplication of principal tidal stations to be avoided.

Ottawa,

April 4, 1907.

TABLE A.—VARIATION IN THE SYNODIC AND ANOMALISTIC MONTHS.

VARIABLE TIDAL DIFFERENCES FOR LOW WATER IN THE ST. LAWRENCE ESTUARY.

(For Calculation of Low Water at Father Point, from Low Water at Quebec.)

Synodic Month

Moon's Phases	No. of Tide	Difference for Low Water H.	M.	Moon's Phases	No. of Tide	Difference for Low Water H.	M.
Full Moon				New Moon	0	5	41
	28	5	41		1	5	42
	27	5	42		2	5	43
	26	5	43		3	5	43
	25	5	43		4	5	42
	24	5	42		5	5	41
	23	5	41		6	5	40
	22	5	40		7	5	38
	21	5	38		8	5	35
	20	5	35		9	5	32
	19	5	32		10	5	29
	18	5	29		11	5	26
	17	5	26		12	5	22
	16	5	22		13	5	19
	15	5	18		14	5	16
	14	5	15		15	5	14
	13	5	12		16	5	12
	12	5	11		17	5	11
	11	5	11		18	5	11
	10	5	12		19	5	12
	9	5	15		20	5	15
	8	5	18		21	5	18
	7	5	22		22	5	22
	6	5	26		23	5	26
	5	5	29		24	5	29
	4	5	32		25	5	32
	3	5	35		26	5	35
	2	5	38		27	5	38
	1	5	40		28	5	40
New Moon	0	5	41	Full Moon			

Total length of Synodic month = 57·06 tide-intervals.

Anomalistic Month

Moon's Distance	No. of Tide	Correction in Minutes	Moon's Distance	No. of Tide	Correction in Minutes
Apogee			Perigee	0	+14
	26	−08		1	+16
	25	−08		2	+17
	24	−08		3	+17
	23	−08		4	+17
	22	−08		5	+16
	21	−08		6	+14
	20	−07		7	+12
	19	−07		8	+10
	18	−06		9	+09
	17	−06		10	+07
	16	−05		11	+06
	15	−05		12	+04
	14	−04		13	+03
	13	−03		14	+02
	12	−02		15	+01
	11	−01		16	0
	10	0		17	−01
	9	+01		18	−02
	8	+02		19	−03
	7	+03		20	−04
	6	+04		21	−05
	5	+06		22	−05
	4	+07		23	−06
	3	+09		24	−06
	2	+10		25	−07
	1	+12		26	−07
Perigee	0	+14	Apogee		

Total length of Anomalistic month = 53·24 tide-intervals.

TABLE B.—VARIATION IN THE DECLINATION-MONTH.

VARIABLE TIDAL DIFFERENCES FOR THE TIDE IN NORTHUMBERLAND STRAIT.

(For Calculation of Pictou tides from St. Paul Island.)

Differences to be *added* to the time of the tide at St. Paul Island, for result in Standard time.

In the numbering, the lower transit tides are enclosed in brackets. The term node is here used to indicate the point at which the moon crosses the equator, in passing from N. to S. declination, and S. to N.

For High Water			For Low Water		
Moon North	Difference	Moon South	Moon North	Difference	Moon South
Number of Tide after Zero declination		Number of Tide after Zero declination	Number of Tide after Zero declination		Number of Tide after Zero declination
Ascending Node	H M	Descending Node	Ascending Node	H M	Descending Node
(0)	1:41	0	0	1:27	(0)
1	1:41	(1)	(1)	1:27	1
(2)	1:41	2	2	1:27	(2)
3	1:41	(3)	(3)	1:27	3
(4)	1:41	4	4	1:27	(4)
5	1:41	(5)	(5)	1:27	5
(6)	1:41	6	6	1:27	(6)
7	1:41	(7)	(7)	1:27	7
(8)	1:37	8	8	1:27	(8)
9	1:41	(9)	(9)	1:18	9
(10)	1:28	10	10	1:27	(10)
11	1:41	(11)	(11)	1:10	11
(12)	1:21	12	12	1:27	(12)
13	1:41	(13)	(13)	1:04	13
(14)	1:16	14	14	1:27	(14)
15	1:41	(15)	(15)	1:00	15
(16)	1:13	16	16	1:27	(16)
17	1:41	(17)	(17)	1:00	17
(18)	1:13	18	18	1:27	(18)
19	1:41	(19)	(19)	1:00	19
(20)	1:16	20	20	1:27	(20)
21	1:41	(21)	(21)	1:04	21
(22)	1:21	22	22	1:27	(22)
23	1:41	(23)	(23)	1:10	23
(24)	1:28	24	24	1:27	(24)
25	1:41	(25)	(25)	1:18	25
(26)	1:37	26	26	1:27	(26)
Descending Node		Ascending Node	Descending Node		Ascending Node

It will be noticed in the table that the difference for high water is constant for all similar tides; that is, for upper transit tides when the moon is in north declination, and for lower transit tides when the moon is in south declination. Also, the least differences or minimum values for both high water and low water, occur at the third tide after the moon's maximum declination; which is the same as the interval at which spring tides occur after full and change of the moon.

This table is for a year of greatest range in the declination of the moon. Similar tables are used for years of least range, and for the mean between the two, in the course of the 19-year cycle.

ERRORS OF TRANSIT OBSERVATIONS.

By R. M. Stewart.

THE object of this paper is to enquire into the magnitude and source of errors in transit observations taken in the ordinary way with a portable instrument; that is, it will refer only to the case in which the azimuth and collimation errors of the instrument must be determined by the observations themselves, and not by means of a fixed azimuth mark and collimating telescopes. For a more complete understanding of the conditions, it may be well to explain in a few words the general method of making such observations which has always been customary at the Dominion Observatory.

The instruments used are the ordinary reversible type of Cooke transit, with object-glass of about three inches aperture and three feet focal length. These instruments, though portable, are heavy and massive enough to be fairly stable during an evening's work. A complete time determination consists of the transits of twelve stars, six in each position of the instrument; of these six, one is a slow-moving north star for the determination of azimuth, while the remaining five are south of the zenith. After applying corrections for level error and for diurnal aberration, we have from each star an equation of the form $Cc + Aa + \Delta T = \tau$, where c and a are the collimation and azimuth errors respectively, C = sec. δ, A = sin. $\varphi - \delta$ sec. δ, and ΔT is the clock correction. The twelve equations are combined by least squares, giving equal weights to the separate observations, and hence are deduced the values of c, a, and ΔT. The probable error of the resulting ΔT is found in the usual way from the residuals given by the separate stars. It has been the usual custom to so select the stars as to "balance" the set, that is, to have ΣA and ΣC each as nearly zero as convenient.

Every one who has had extended experience with such

observations has noticed certain discrepancies which frequently show themselves in the results. In an extended series of observations for personal equation, the different values obtained, even from two determinations on the same night, may sometimes, if not frequently, differ by a tenth of a second or even more; while the probable errors of the individual sets may not in any case exceed one one-hundredth of a second. Nor is it only in personal equation observations that these discrepancies show themselves; in longitude determinations, a fair average of the extreme differences obtained during a few nights' work would probably be about a tenth of a second or more; and the differences in clock-error obtained by the same observer on the same night from successive determinations, even when using a reliable clock, are often of about the same order of magnitude.

From a comparison of the magnitude of these frequent discrepancies with that of the corresponding probable errors, and from the fact that they do not follow the same law, and seem to have no connection, it is at once evident that the discrepancies are not the result of truly accidental errors, but are systematic in their nature; that is to say, that of two sets taken on the same night, one may be affected by a certain systematic error, the other by a different error, also systematic. The simplest explanation of this fact, and the one which has been generally accepted*, is that these discrepancies are the result of real variations in the observer's personal equation. Such a supposition would fully and absolutely explain the observed facts; for even though the change were a gradual and regular one during any single night it would not be evident from a consideration of the separate observations, for the reason that the grouping into sets and the separate reduction of these would tend to mask its progressive character. And further, if the discrepancies were due to this cause, we should naturally expect that in observations with the travelling-wire micrometer, which are practically free

* See "Test of a Transit Micrometer," U.S. Coast and Geodetic Survey report, 1904; also "Die Beobachtungsmethode mittelst des Repsold'shen Registrirmikrometer in ihrer Anwendung auf Längenbestimmungen," by Prof. Th. Albrecht, in Astronomische Nachrichten, No. 3699, Band 155.

from personal error, they would disappear or at least be considerably reduced. It remained, then, only to test this hypothesis by actual experiment.

Two of the instruments belonging to the Observatory had been equipped with the micrometer attachment for a couple of seasons ; but most of the observations taken with them had been in the field, and the variations in the rates of the chronometers used made it impossible to place any dependence on conclusions drawn from these data. There remain some observations for personal equation taken here by Mr. McDiarmid, using the Riefler Sidereal Clock, which might have been compared with observations taken by the writer at the same time with the key. But any conclusions based on these data could scarcely have been final, for whichever way the balance went, the possibility would remain of explaining it by the superior accuracy of one or the other observer. Consequently it was decided to make a test by conducting a series of observations with two instruments, one fitted with a transit micrometer, the other with a fixed field and a key. The method followed was to take as many time sets as convenient, four if possible, on the same night, with the key and micrometer alternately, repeating the programme on a sufficient number of nights. The accurate running of the Riefler Clock made it possible to compare rigorously the results of all the observations on any night, and even, with some slight reservation, on succeeding nights.

This series of observations was begun about the middle of December last, and concluded early in February ; during that time some forty-five sets had been observed on sixteen different nights, nearly an equal number with each instrument. It was not possible, on account of weather conditions, to adhere throughout to the full programme of four sets on every night ; sometimes only three or two were obtained, and on a few occasions only one. It was hoped, however, that even these might be made some use of, if the clock-rate proved constant enough from day to day. The results are shown in Table I. The second and third columns show respectively the clock-correc-

tions (in seconds) and their probable errors as deduced in the usual way ; the fourth and fifth columns contain the discordances between the different observations on the same night with the same instrument. These range in the case of the key up to ·129 sec., with an average of ·049 sec.; in that of the micrometer to ·103 sec., with an average of ·045 sec.; the average probable error is ·011 sec. for each instrument. It is worthy of note that on Dec. 17th, when the largest discrepancy with the micrometer occurred, the probable errors of the two sets were only ·009 sec. and ·011 sec., while the discrepancy of ·129 sec. with the key occurred between two sets whose probable errors were ·007 sec. and ·011 sec.

We may examine this series of observations in another way, which will give perhaps a better comparison of the performances of the two instruments. It has been mentioned that the standard clock of the Observatory has a very steady rate ; if it should so happen that the series of observations with one instrument showed a pronounced tendency to agree more closely with the supposition of a regular rate-curve, that would indicate, other things being equal, that that series of observations was less affected by fluctuating errors. From the values in column II. we can obtain the mean systematic difference between the key and micrometer observations, a quantity which of course corresponds to personal equation ; it amounts to ·445 sec. The application of this correction to the key observations makes all the observations on any single night strictly comparable ; the derived values are given in column VI., and the means for each night in column VII. From a consideration of these it is apparent that as regards clock-rate the whole period falls naturally into three parts, during each of which the rate was more or less constant. With the causes which gave rise to the changes in rate between the successive periods we are not especially concerned here ; it is sufficient for our purpose that during each of the first two periods the evidence points to a practically constant rate, so that we are enabled to make a comparison of all the observations without regard to date ; during the last

few days there were some causes which gave rise to fluctuations in rate, as is indeed evident from column VII. During the first period (Dec. 17 to Jan. 11) the mean rate was −·0074 sec. per day; during the second (Jan. 11 to Jan. 28), +·0359 sec. per day. The theoretical clock corrections at these constant rates are given in column VIII., while column IX. exhibits the differences between columns VII. and VIII. The smallness of these differences at once gives color to the supposition that the rate was practically uniform during each period, and allows us without fear of error to make use of the test above referred to. This consists in a comparison of the residuals of each separate observation from the assumed rate-curve; these are tabulated for the two instruments in columns X. and XI. The mean value for the key is ·028 sec., and for the micrometer, ·029 sec., the largest values being ·078 sec. and ·059 sec. respectively.

This series of observations, then, in whatever way we examine it, points to the conclusion that so far as irregular variations are concerned, there is very little to choose between the key and the micrometer. True, the values are on the whole perhaps slightly smaller in the case of the micrometer, but the difference is so slight that we would not be justified in drawing any conclusions from it.

In order to check the conclusions arrived at, an investigation was made of all the available micrometer observations made at the Observatory; those taken in the field were useless for the purpose as stated before, on account of the inaccuracies of chronometer rate. The entire data were found to consist of thirteen nights' work, on each of which two time sets had been taken. These nights were distributed over several months; the largest discrepancy which occurred was ·108 sec., the average value being ·035 sec., while the average of the probable errors of all the sets was ·010 sec. From fifteen nights' key observations taken during the same period the largest discrepancy was ·101 sec., the average being ·034 sec., and the average probable error ·010 sec. In this case the discrepancies are somewhat smaller

than those obtained in December and January, as was of course to be expected from the difference in temperature and the consequent difference of comfort in making the observations. As in the former case, however, the values are practically the same for the two methods of observing.

The conclusion, then, would appear to be forced upon us, that if irregular fluctuations of personal error do occur in key observations, their influence is effectually masked by some other source or sources of error which are common to observations with the transit micrometer. This is, so far as the writer is aware, the first comparative test of the kind to be made under identical conditions for both instruments, and it is perhaps not surprising that what seems to have been an erroneous assumption should have been made; indeed, the present investigation was undertaken in the first place with the firm expectation of merely confirming the generally accepted opinion. These conclusions, however, it must be remembered, do not invalidate the claim for the micrometer of the practical elimination of personal equation and all the advantages thereby entailed.

Taking it for granted, then, that these effects are practically independent of the instrument used, and therefore not due to variations of personal equation, there remains the larger question whence they arise. We must evidently look for some source of error which from its nature would not show itself in the residuals, which might systematically affect the result of a complete set by a considerable quantity, and which might vary from one set to another.

In considering the question *a priori*, the explanation seemed most likely to lie in defective determinations of azimuth caused by errors in the observations of polar stars; this view was strengthened by the reflection that when the azimuths of the two "clamps" of a time set are reduced separately, they frequently differ by a considerable amount. A simple test of the validity of this explanation can be obtained by observing in the course of a set as large a number of polar stars as possible, and examining the effect of a choice of different ones in reduction.

Table II. shows the result of such observations and reductions on a number of nights. In most cases four polars and from six to ten time stars were observed in each set; the polars were in every case ones that might have been used in the course of ordinary observations—*i.e.*, ranging from about 75° to 85° declination. The reduction was made first with one pair of polars, omitting the others, and afterwards with the other pair and the *same* time stars. The second and third columns give the clock corrections and azimuths obtained in this way from each set, the fourth column containing the probable errors of the corresponding clock corrections. In the last column is given the difference between the two time determinations from each set. It will be seen that in three cases out of the nine the two values of the azimuth differ by over a tenth of a second of time, or one and a half seconds of arc, while in four cases the resulting effect on the time determination is about ·05 sec. or over. In some cases almost as large a change would have resulted by replacing only one of the polars, though in the majority of cases each separate polar gives a quite distinct value of the azimuth.

There can be no doubt that we have here the principal source of error in such observations as we have been considering. While in itself it may not be of sufficient magnitude to completely account for all the discrepancies observed, it would seem to do so fully when taken in conjunction with ordinary accidental errors of observation and with the errors arising from defective level readings, which, however, it greatly overshadows in magnitude. The fault does not appear to lie, at least in the main, in catalogue errors or in magnitude equation, but simply in accidental errors of observation of the polar stars, which of course become systematic with respect to any one set. It remains to be seen whether any method of observing can be devised to overcome the difficulty. Some tentative experiments have been made to this end, and the subject may be further considered in a future article.

I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Date	ΔT	r	Discordances		ΔT_o	Mean for night	ΔT at mean rate	Resid. for night	Residuals	
			Key	Microm.					Key	Microm.
Dec. 17	−2·704	·009			−2·704					−·059
" 17	3·070*	·011	·024	·103	2·625*	2·645	−2·645	·000	·020	
" 17	3·094*	·012			2·649*				−·004	
" 17	2·601	·011			2·601					·044
Dec. 19	2·612	·013			2·612					·047
" 19	3·182*	·011	·129	·068	2·737*	2·659	2·659	·000	−·078	
" 19	3·053*	·007			2·608*				·051	
" 19	2·680	·011			2·680					−·021
" 27	3·165*	·012			2·720*	2·720	2·719	−·001	−·001	
Jan. 2	3·211*	·010			2·766*	2·766	2·763	−·003	−·003	
Jan. 6	2·746	·009			2·746					·047
" 6	3·281*	·004			2·836*	2·791	2·793	·002	−·043	
Jan. 9	2·803	·015			2·803					·012
" 9	3·221*	·015	·015	·017	2·776*	2·797	2·815	·018	·039	
" 9	3·236*	·015			2·791*				·024	
" 9	2·820	·014			2·820					−·005
Jan. 11	2·856	·007			2·856					·026
" 11	3·308*	·007	·046		−2·863*	2·845	2·830	−·015	−·033	
" 11	3·262*	·012			2·817*				·013	
Jan. 15	2·721	·008			2·721					−·037
" 15	3·107*	·009			2·662*	2·691	2·684	−·007	·022	
Jan. 16	2·617	·013			2·617	2·617	2·647	·030		·030
Jan. 18	2·562	·013			2·562	2·562	2·573	·011		·011
Jan. 21	2·508	·010			2·508					−·046
" 21	2·899*	·009	·063		2·454*	2·493	2·462	−·031	·008	
" 21	2·962*	·009			2·517*				−·055	
Jan. 23	2·778*	·013			2·333*				·055	
" 23	2·409	·012	·034	·007	2·409	2·378	2·388	·010		−·021
" 23	2·402	·015			2·402					−·014
" 23	2·812*	·012			2·367*				·021	
Jan. 28	2·214	·020			2·214					−·010
" 28	2·641*	·013			2·196*	2·205	2·204	−·001	·008	
Jan. 30	2·452*	·008			2·007*					
" 30	2·044	·007	·040	·066	2·044	2·019				
" 30	1·978	·011			1·978					
" 30	2·492*	·010			2·047*					
Feb. 4	1·515	·011			1·515					
" 4	1·967*	·013	·064		1·522*	1·541				
" 4	2·031*	·011			1·586*					
Feb. 6	1·670*	·008			1·225*					
" 6	1·169	·007	·008	·011	1·169	1·198				
" 6	1·180	·012			1·180					
" 6	1·662*	·014			1·217*					
Means		·011*	·049	·045					·028	·029
		·011								

* Key observations.

TABLE II.

Date	$\Delta T'$	a	r	Diff.
Dec. 19	− 2·654	− ·060	.016	·073
	− 2·581	− ·196	·013	
Dec. 19*	− 3·182	·485	·012	·069
	− 3·113	·360	·016	
Feb. 21	·122	− ·244	·008	·013
	·135	− ·264	·008	
Mar. 6	·608	·317	·010	·046
	·744	·244	·014	
Mar. 25	− ·655	− ·349	·019	·018
	− ·637	− ·398	·017	
Apr. 14	4·095	− ·204		·021
	4·116	− ·249		
Apr. 15	4·035	− ·158		·070
	4·105	− ·329		
Apr. 19	17·914	− ·218		·028
	17·942	− ·284		
July 2*	17·809	·108	·012	·016
	17·825	·082	·012	

* Key observations.

THE SPECTROSCOPIC BINARY α DRACONIS.

W. E. Harper.

THE star α Draconis R. A. = 14h 1·7m, δ = +64° 51′. Visual Mag. 3·6, Phot. Mag. 4·0 has been under observation here intermittently since July 1906. Up to Feb. 12 of this year 37 spectrograms in all had been secured. The radial velocities obtained from the measurement of these were used to obtain provisional values for the elements of the star's orbit. These provisional elements were announced in a previous number of this Journal.

In drawing the original curve more or less difficulty was experienced from the fact that there were certain intervals for which, owing to unfavourable weather, there had not been any corresponding observation. This was particularly the case at the maxima and minima. Furthermore since the measurements for velocity on the spectrograms already obtained were for the most part dependent on three lines; a faint *Fe* λ 4549, a sharp Mg. λ 4481 and a broad diffuse H_γ λ 4340, the resulting velocity was liable to be in error to the extent of say 5 kms. per sec. Three of the plates gave residuals from the computed velocity curve of upwards of 10 kms. but owing to the few lines in the spectrum this large discrepancy may probably be ascribed to accidental distortions of the photographic film, or it may be that the character of the spectrum of the star may have had something to do with the large residuals, as at times an apparent doubling of some of the lines was noticed. At any rate when the new spectrograph was put into regular use about the middle of May the time seemed opportune for securing more spectrograms of this star. This spectrograph with the single-prism attachment gives a flat field from about λ 3600 through the whole range of the visible spectrum. Although its linear dis-

persion is much less than that of the old spectrograph, the number of additional lines that can be measured *e.g.* H_β λ 4861, H_δ λ 4102 and H_ε λ 3970 renders the resulting velocity much less liable to error than would be the case with the former spectrograph. Nine more spectrograms have thus been secured, most of which fall in the gaps already alluded to.

With the exception of the more recent negatives, for which a newer and shorter method has been evolved, the spectrograms have all been reduced by means of the Hartmann interpolation formula

$$\lambda = \lambda_\circ + \frac{c}{s_\circ - s}$$

where λ is the apparent wave-length of the line measured, s is the micrometer reading, and $\lambda_\circ$, c, $s_\circ$ are constants determined from known standard comparison lines with their corresponding micrometer readings. The difference between the measured wave-length of the stellar line and its normal wave-length gives us the displacement $d\lambda$ due to the approach or recession of the star. This displacement is easily converted into velocity by means of the simple formula

$$V_r = \frac{299{,}860}{\lambda} \cdot d\lambda.$$

where V_r is the required radial velocity. To this velocity is then added a correction V_a due to the orbital motion of the earth and another V_d due to its axial rotation. No allowance is made for the motion of the solar system through space; the resulting velocities are therefore relative to the sun.

For the sake of brevity the Journal of Observations is omitted. The exposure time required in fair seeing was about 30^m with the single-prism, and about 55^m with the three-prism instrument, the slit-width being usually ·025 mm. Several plates were made on each of the nights Nov. 1, Nov. 6 and Nov. 8. I suspected that the star might have a very short period but the measures showed no rapid change of motion such as might be looked for in a short period binary

and accordingly the mean of these measurements for each night was used. In the summary of velocities which follows the phase is given with each velocity. This is the time-interval after some initial epoch selected arbitrarily. I have taken the initial epoch when the computed velocity is zero and becoming positive, *i.e.*, T_0 = 1906, July 2, G.M.T., 0^h.

SUMMARY OF VELOCITIES.

Date	Phase	Velocity	Date	Phase	Velocity
1906					
July 2·67	0·67	+ 3	Dec. 17·75	14·61	- 7
" 4·75	2·75	+ 16	" 18·75	15·61	- 17
			1907		
Aug. 15·59	44·59	- 32	Jan. 9·67	37·53	- 43
" 24·59	2·20	+ 6	" 11·75	39·61	- 35
			" 21·67	49·53	- 6
Sep. 10·59	19·20	- 30	" 30·71	7·19	+ 44
" 19·59	28·20	- 42			
" 27·54	36·16	- 42	Feb. 6·75	14·23	- 4
			" 12·62	20·10	- 36
Oct. 3·5	42·12	- 39			
" 18·5	5·74	+ 32	May 22·64	16·57	- 18
			" 31·68	25·41	- 38
Nov. 1·6	19·76	- 40			
" 6·6	24·77	- 44	June 8·78	33·50	- 45
" 8·6	26·76	- 45	" 10·7	35·42	- 31
" 16·67	34·91	- 50	" 11·6	36·32	- 42
" 19·54	37·78	- 54	" 20·64	45·36	- 20
			" 21·69	46·41	- 21
Dec. 7·71	4·57	+ 31			
" 11·8	8·65	+ 31	July 4·63	7·96	+ 56
" 13·54	10·40	+ 34	" 5·62	8·96	+ 45

These values when plotted give us a period of about 51 days. To determine the period with greater accuracy it is necessary to take a series of observations extending over a long time and to divide the interval by the number of periods. For this purpose, of course, the longer the star is under observation the more accurately can the period be determined. Our observations extend over only seven periods, whereas observations made at other observatories taken in conjunction with our own give a range of over forty periods.

The following are the only other observations made on this star, which are known to the writer.

PREVIOUS OBSERVATIONS.

Date	Phase	Velocity	Observatory
1901 Nov. 20·92	11·46	+20	Yerkes
1902 June 16·6	13·82	+ 1	Lick
1903 Apr. 29·	22·54	−43	"
" May 4·	27·54	−42	"
" " 23·	46·54	−17	Potsdam
" " 24·	47·54	−14	"
1904 June 19·	28·50	−42	Lick
1905 " 13·	27·84	−42	"
1906 Jan. 4·	27·22	−40	"
" " 5·98	28·47	−42	Yerkes
" " 8·9	31·43	−55	"
" " 26·89	49·41	− 9	"
" " 29·81	0·95	+ 1	"
" Feb. 9·93	12·07	+24	"

Reducing all the observations within the same period, we find

$$P = 51^{d}{\cdot}38$$

which is likely not much in error.

It now remains to determine the remaining elements of the orbit from the curve shown. There are two methods; the geometrical, in which the elements are obtained from a consideration of the curve itself, its maximum and minimum points especially, and the areas enclosed by certain portions; the analytical, in which we have recourse to a Fourier series. The former method is that of Lehmann-Filhés; the latter is due to Russell. For orbits of small eccentricity the latter is the preferable I fancy, but in other cases the geometrical is more suitable. I have used the analytical method, and I shall briefly summarize it; Mr. J. S. Plaskett has computed the elements by the

other method, and a comparison of the two will prove interesting.

The velocity being a known periodic function of the time can be expressed in the form of a series of sines and cosines. Thus we may write

$$v = c_0 + c_1 \cos.\ \mu\,(t - t_0) + c_2 \cos.\ 2\,\mu\,(t - t_0) + + \\ + s_1 \sin.\ \mu\,(t - t_0) + s_2 \sin.\ 2\,\mu\,(t - t_0) + +$$

where c_0, c_1 ..... s_1 s_2 ..... are constants determined from the curve, t the time at which the velocity is v, and t_0 the initial epoch. With a slight transformation this series can be put in the form

$$v = a_0 + a_1 \cos.\ [\mu\,(t - t_0) + \alpha_1] + a_2 \cos.\ [2\,\mu\,(t - t_0) + \alpha_2] + \ldots\ldots \quad (1)$$

in which the a's and α's are determinable from the c's.

To get an analytical expression for the velocity let our fixed plane of reference be the one perpendicular to the line of sight, let

a = semi-major axis of the orbit
e = eccentricity
i = inclination of plane of orbit to our plane of reference
ω = longitude of periastron measured from the descending node
T = time of periastron passage
θ = true anomaly
M_0 = mean anomaly at time t_0
r = radius vector
V_0 = velocity of system of the whole.

We can then get the following expression for the velocity

$$v = V_0 + \mu\,a \sin.\ i\,b_1 \cos.\ [\mu\,(t - t_0) + \beta_1 + M_0] + \mu\,a\,e \sin.\ i\,b_2 \cos.\ [2\,\mu\,(t - t_0) + \beta_2 + 2\,M_0] + + \ldots\ldots \quad (2)$$

The series (1) and (2) considered as functions of the time are of the same form. If they are to represent the same quan-

tity their corresponding coefficients must be equal. Considering terms of e no higher than the first we immediately get preliminary values of V_0, e, ω, $a \sin. i$ and M_0 from which by a series of approximations newer and more accurate values can be obtained.

From the first curve arbitrarily drawn were obtained the elements

$$\begin{aligned} e &= 0{\cdot}40 \\ \omega &= 197^\circ\ 16{\cdot}8 \\ V_0 &= -\ 16{\cdot}9 \text{ kms.} \\ T &= 1906 \text{ July } 10{\cdot}69 \end{aligned}$$

These elements in turn were used to compute an ephemeris by using the two following equations:—

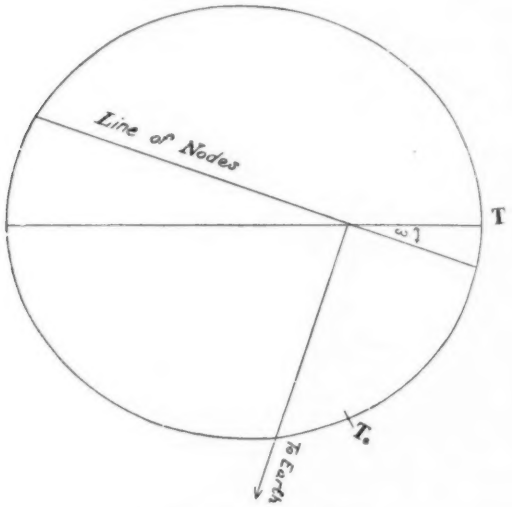
$$t = \frac{P}{2\pi} \cdot 2 \tan.^{-1} \sqrt{\frac{1-e}{1+e}} \tan. \frac{\theta}{2} - \frac{e \sqrt{1-e^2} \sin. \theta}{1 + e \cos. \theta}$$

$$v = \frac{A+B}{2} \cos. (\theta + \omega) + \frac{A-B}{2},$$

where t is the time required to describe an angle θ from periastron, v the corresponding velocity, A and B being velocities as designated in the Lehmann-Filhés method. By using values of θ differing by 10° thirty-six points were obtained through which the computed velocity curve was drawn. An examination showed that the original observed velocity curve could be brought into better agreement with the computed curve and still be in as good, if not better, accord with the observations. This was done and a new set of elements computed from this curve. These elements, differing slightly from the previous ones, were in turn used to obtain a second computed velocity curve. The agreement between these latter curves was much better than formerly but was still unsatisfactory. An increase in ω and T would improve matters and when this was done the agreement, though still imperfect, was fairly satisfactory.

The residuals of all our observations from this second computed velocity curve were now taken and the probable error of a

single observation $r = \pm 6745 \sqrt{\frac{\Sigma v^2}{n-1}}$ was computed. Our own observations gave $r = \pm 3{\cdot}4$ kms. but if the three discordant observations mentioned previously were omitted this was reduced to 2·6 kms. For the previous observations recorded $r = \pm 3{\cdot}6$ kms. but if we omit a discordant one of Frost's this would be lessened to 2·9 kms. For a star of this type this may be considered quite satisfactory.



ORBIT OF α DRACONIS.

Following out the geometrical method Mr. Plaskett used his provisional elements to correct his original curve, from which corrected curve he determined his second and final set of elements. The agreement between his observed and computed velocity curves on this second approximation was sufficient without any further changes and I believe that for an orbit of eccentricity as great as this one under consideration the geometrical method is much preferable. The table of elements as determined by each follows :—

TABLE OF ELEMENTS.

Elements	Harper	Plaskett
P	$51^{d}\cdot38$	$51^{d}\cdot38$
V	- 16·7 kms.	- 17·0 kms.
e	0·42	0·44
ω	198° (from descending node)	20° 15′ (from ascending node)
T	1906 July $11^{d}\cdot0^{h}$	1906 July $11^{d}\cdot0^{h}$
$a \sin. i$	30,057,900 kms.	29,683,000 kms.

Both sets of curves are shown; my own in Fig. I. and Mr. Plaskett's in Fig. II. The heavy line is the observed velocity curve while the dotted is the computed one. The small circles represent our own observations while the dots are those of other observers. A graph of the orbit is also shown.

No attempt has been made to correct the elements by the method of least squares as the observations were not considered to be of sufficient accuracy to warrant such a procedure.

I acknowledge with thanks my indebtedness to Mr. J. S. Plaskett, who throughout has given me much valuable advice and assistance; and I am glad also of this opportunity of expressing my appreciation of the kindly interest which the Chief Astronomer, Dr. W. F. King, has shown in the prosecution of this work.

Dominion Observatory,
Ottawa, Canada,
July, 1907.

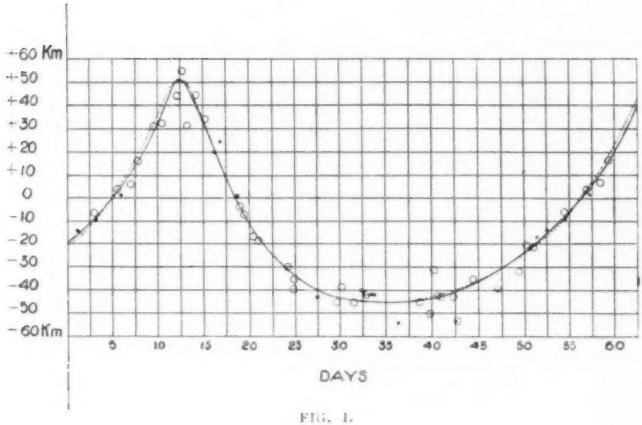


FIG. I.

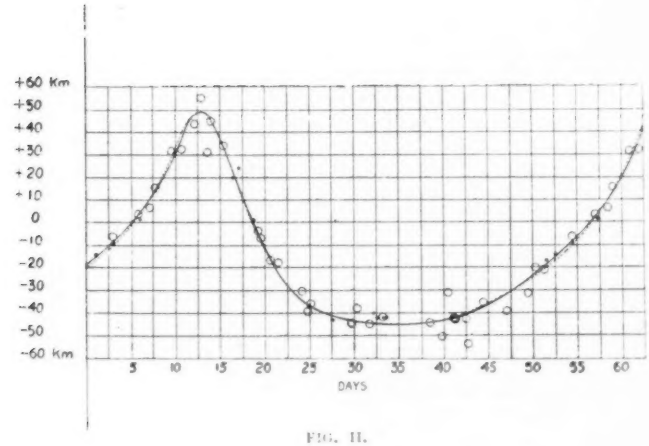


FIG. II.

VELOCITY CURVES OF α DRACONIS.

WORK AT THE LICK OBSERVATORY AND IMPROVEMENTS IN ITS EQUIPMENT.

By C. A. Chant.

IN the following pages an attempt is made to give a general account of the work being carried on at the Lick Observatory and of some recent additions to its equipment.

IMPROVEMENTS IN BUILDINGS AND EQUIPMENT.

(a). *A Photographic House.*

The plans for the observatory were made in the late '70's, and executed in the early '80's, at which time astronomers did not realise the important part which photography was destined to play in their researches. Consequently when the institution was opened on June 1, 1888, it did not possess suitable rooms and apparatus for taking celestial photographs or for their study and measurement. The first director, Professor Holden, soon found it necessary to transform the observatory equipment to meet the photographic requirements. Fortunately considerable gifts from outside sources as well as small sums from the maintenance funds allowed the provision of photographic telescopes, spectrographs and measuring microscopes. Space suitable for the manipulation and study of photographs has always been wanting, and the successive annual reports of Directors Holden, Keeler and Campbell have drawn attention to the need of a building in which the rapidly growing collection of photographs could be stored, and which would supply proper facilities for the enlargement and measurement of photographic plates. This pressing need is soon to be satisfied. Plans for a building to cost about $22,000 have been prepared, and the Legislature of the State of California has appropriated $10,000 to begin the work, which, it is hoped, the succeeding Legislature will complete. The building will be of re-enforced concrete, and the portions to be used for storage purposes will be made as nearly

fireproof as possible. The structure will be 52 feet long by 31 feet wide, and two stories high. It will contain four storage vaults, an enlarging room 50 feet in length, three dark-rooms, a room for testing new apparatus and two rooms for the measurement of photographs.

(b). *Electrical Equipment.*

The observatory began its work also without any electrical equipment. In 1891 Mr. Thomas A. Edison presented the institution with a complete outfit, consisting of a dynamo of one kilowatt capacity, together with steam engine and boiler, storage battery, switchboard and wiring. This small plant supplied current for the comparison apparatus and temperature-control of the spectrographs, for the illumination of the setting-circles and the micrometer wires of the principal telescopes,—that is, for the more pressing scientific needs. The lighting of the observatory buildings has been by oil lamps.

The small Edison plant has long been inadequate even for scientific purposes, and it was felt also that the heterogeneous combination on the mountain of steam, water, wind and gasoline driven engines for various purposes was uneconomical both of time and money, and at last the Legislature of two years ago appropriated the sum of $10,000 to supply an electrical equipment to meet the numerous and varied requirements. A 20 h.p. gasoline engine is directly connected to a dynamo, which is used to charge a storage battery of 128 cells, each having a capacity of 200 ampere-hours. This acts as a reservoir, to be drawn upon as required. The greater part of the installation was made in 1906, but owing to the extraordinary conditions of labor and supplies, following the earthquake and the great fire in San Francisco, it was not completed until the present summer. Apart from the current for purely scientific purposes, it will be used to turn the domes of the great refractor and the Crossley reflector, to wind their clocks, to run the machinery in the instrument and carpenter shops, to work two pumps of the water-supply and to saw fuel for the community. Already it illu-

minates the main building, (with its 36-inch and 12-inch refractors,) the meridian circle house, the Crossley, six-inch and Crocker telescope houses, the workshops, and also ten residences and outbuildings. This electrical plant is perhaps appreciated all the more because of the long time required to get it.

(c). *The Water Supply.*

When it is remembered that the summit of Mt. Hamilton is 4200 feet above the sea and that the entire community live on the observatory property, it will be seen that the task of supplying comfortable accommodation and the ordinary necessities of modern life is not a simple one. At most observatories when funds are available for an assistant's salary the director chooses the best man available and allows him to make his own living arrangements. Not so with the Lick Observatory. Here the Director must first inquire the size of the applicant's family, as there is no other place for him to live but in an observatory house, and the space is very limited.

One of the most important problems is that of the water supply. At first the community had from twelve to twenty inhabitants and the water supply question was found to be difficult enough, but now when the inhabitants number from 55 to 60 it is much more serious.

The source of supply up to the present has been a spring located about one mile from the observatory buildings and 300 feet below their level. This spring could supply more than the amount required in the wet season, but much less than is needed in the long rainless summer. Storage capacity of 160,000 gallons exists on a peak fifty feet higher than the main buildings and half-a-mile distant from them. Careful attention to the piping, in order to prevent leaks, has enabled the system to supply the modest demands, provided the rainfall has been of average amount. In some seasons, however, this has not been the case, and then the domestic and photographic services had to go on short allowance. On two occasions the situation has been difficult. Moreover, the shortage always happens at the end of the long dry season, when fire risks are greatest. The

Legislature recently made a small appropriation for the development of another spring, which, though 350 feet lower than that hitherto used, has an output perhaps fifteen-fold greater. It is located on a 30° slope, at a level 680 feet below the reservoir system. It may be of interest to outline the pumping system employed in raising the water. First it is led into small reservoirs placed a few feet below the level of the spring, and from these a pipe leads the water to a point 215 feet lower in level, where an automatic pump is installed. The water-head of 215 feet operates the motor-end of the pump in exactly the same way that steam performs in ordinary pumps. The motor pistons are directly connected to the pumping pistons, the cross-section of the latter being one-sixth that of the former. The supply for the pumping pistons reaches them likewise under a head of 215 feet. Connected to the pumping chamber is the delivery pipe, which runs up the slope to the storage reservoir on the summit. It will thus be seen that of every seven gallons six operate the pump and the seventh is delivered at the summit. On account of the large flow of the spring the available water supply has been multiplied three-fold.

Several improvements are projected as a result of the increased supply, for example, the foresting of several of the slopes leading down from the observatory, involving irrigation during the first few dry seasons.

(d). *Alterations to the Crossley Reflector.*

An addition to the optical system of the Crossley reflector is under way, in order to adapt this powerful instrument to the requirements of parallax and spectrographic work. At present the system consists exclusively of the excellent 36½-inch silver-on-glass mirror, which has a ratio of aperture to focal length of 1:5·8. This ratio is not suitable for the collimator of a spectrograph, and likewise the scale of stellar photographs is too small to admit of the very accurate observations required in parallax determinations. Mr. F. G. Pease, formerly assistant to Professor G. W. Ritchey, and now expert optician to the Scientific Shop in Chicago, is on Mt. Hamilton, constructing a 9¾-inch

hyperboloidal secondary mirror in order to convert the telescope into the Cassegrainian form. A third mirror with flat surface will be mounted diagonally, immediately in front of the parabolic mirror, in order to direct the beam of light through the side of the telescope tube near the lower end. The course of the light is thus as follows: Passing down the tube it reaches the great parabolic mirror, by which it is returned along the axis of the tube to the hyperboloidal mirror, which again returns it to the plane reflector placed near the large mirror. By this it is turned at right angles, and emerges through an opening in the side of the tube. Here it will be received on the photographic plate, or in the eye-piece. The equivalent focal length will thus be increased to about 75 feet. Professor Perrine is hoping promptly to utilize the telescope thus modified in the development of stellar parallax methods, and Director Campbell is planning for spectrographic work on certain especially interesting types of stars.

SPECTROGRAPHIC DETERMINATION OF THE VELOCITY OF STARS IN THE LINE OF SIGHT.

The most extensive investigation under way at the observatory is that of determining the radial velocities of the brighter stars by means of the Mills spectrograph attached to the 36-inch refractor, in accordance with the programme entered upon by Professor Campbell in 1896. This programme embraces all the stars, whose photographic magnitudes are equal to or brighter than 6·0, lying north of $-25°$ declination, with the addition of essentially all of the stars brighter than the 5th magnitude between $-25°$ and $-30°$ declination. The number of stars on the list is approximately 750, though a certain number of these are not amenable to accurate observation, for the reason that their spectra do not contain sharply-defined lines. It is of interest to note that the efficient apparatus in use is capable of recording spectra of 6·0 photographic magnitude stars in good strength with an exposure of 2½ hours, provided the atmospheric conditions are average.

The number of spectrograms secured to date is approximately 4,800, not including several hundred spectrograms, principally of variable stars of the *δ Cephei* type, obtained with an excellent one-prism spectrograph. All of these plates have been submitted to approximate measurement and reduction, and fully two-thirds have been measured and reduced definitively. Since the year 1896 an average of three nights per week have been devoted to the observations. The labor of measuring and reducing a spectrogram is in general two or three times that of obtaining it. For a year and a half Professor Campbell was alone in the work. For five years he was assisted by Professor W. H. Wright, and during the last three years the Carnegie Institution has given support for the employment of assistants in measuring and reducing the plates.

The degree of accuracy attained is simply astonishing, that for the stars of the 5th or 6th magnitude being little inferior to that for the brighter ones. Early in 1901 the results thus far secured were combined mathematically for the determination of the direction and speed of the motion of the solar system in space. This was the original chief purpose of the undertaking and is so yet. However, the by-products of the work, more or less unexpected, are considered by some to be no less important than the determination of the solar motion. For example, the surprising result was soon reached, confirmed amply by work of later years, that at least one star out of six or seven, on the average, has a variable velocity which, passing rapidly through its cycle of changes, shows that the star is a spectroscopic binary. In no case have the components of such a star been observed directly with the telescope, and it is perhaps too much to hope that any of the systems thus discovered by the spectrograph will permit of telescopic resolution.

The proportion of spectroscopic binaries will probably increase rather than diminish as the work proceeds, for the discoveries thus far made relate only to those whose periods are relatively short and whose range of velocity is great. In recent years a considerable number of stars that were originally sup-

posed to have constant speeds are showing changes, indicating that here we are dealing with systems of long period. As the work progresses the suspicion becomes more pronounced that the solar system may not be an average type of stellar system, but may in fact be near one extreme in a long series of different types.

During the organisation of the programme of work with the Mills spectrograph Director Campbell was impressed with the need of similar observations on the stars not accessible to northern observers before a satisfactory solution of the solar motion could be attained. Let the observations of stars in the northern two-thirds of the sky be as extensive and accurate as it is possible to make them, the solution would be incomplete and unsatisfactory so long as the one-third of the stars about the south pole were not included in the solution. The observations in the northern hemisphere could not have their full strategic value until they were combined with corresponding observations in the south polar region.

From the year 1894 Professor Campbell definitely held in mind the desirability of despatching an expedition to secure these observations. In 1900 the time seemed to have come for undertaking this work, and he was fortunately able to enlist the interest and support of D. O. Mills, Esq., who provided the funds completely to meet the requirements of such an expedition. In that year Professor Campbell was made director of the observatory, and it devolved upon his chief assistant in the spectrographic work, Professor Wright, to go in charge of the expedition. The Mills Observatory was located on the summit of a low mountain near Santiago, Chile; and here was completed the original programme of observations, involving 145 stars south of declination -25°, whose spectra contained well-defined lines. The number of spectrograms secured was 800, and the number of spectroscopic binaries discovered by Professor Wright is, as in the north, one in every six or seven stars. The measurement and reduction of the Chile plates has been the chief work of Messrs. Wright and Albrecht on Mt. Hamilton

during the last year, and more than three-fourths of the spectrograms have been completed. The end of this work should be reached in a few months.

The need for many more observations of this kind in the southern hemisphere is very pressing, both to improve our knowledge of the solar motion, and to assist in the solution of other leading problems concerning our sidereal system. The Mills Observatory is equipped especially for this work, and when the subject was brought to the attention of Mr. Mills he was pleased to provide for its continuance for five more years. During this second period the southern work is in charge of Dr. Heber D. Curtis, who assisted with the Mills spectroscope on Mt. Hamilton for three years. The accuracy reached in the Chile work is substantially equal to that on Mt. Hamilton.

One significant fact may be mentioned in connection with the work in the southern hemisphere. For the first time a reflecting telescope, whose arrangements differ in many important respects from those of the conventional instrument, was employed in radial velocity determinations. The spectrograph likewise involved a number of departures that at the time of its construction were new. It was planned definitely to assemble the telescope and spectrograph complete on Mt. Hamilton, to submit them to critical tests, in order that the many unexpected defects and difficulties might be isolated and removed. But an error in figuring the mirrors rendered this assembling and testing on Mt. Hamilton impossible. The unassembled apparatus was shipped to Chile, it was mounted in place at the observing station, far from the services of expert mechanicians and opticians, and there first submitted to test. The significant point is that the programme of observations with the apparatus was carried through substantially as planned, with the accuracy hoped for, without experiencing any serious difficulties and without introducing any single important change in the apparatus. This certainly shows that the elements of the problem of determining the radial velocities of stars with great accuracy have for several years been fully comprehended.

With this great problem of radial determinations the names of Campbell, Lick Observatory and Mills will always be honorably associated, but the Director's greatest satisfaction is not in the fact that the important work is now moving definitely to a conclusion, but that he has trained a considerable number of men who are well qualified to carry on similar researches both in the matter of observation and reduction. In this connection the names should be mentioned of Messrs. Wright, Curtis, Moore, Burns and Albrecht, as well as several who have left the observatory to accept appointments elsewhere.

ECLIPSE EXPEDITION, JANUARY 1908.

Since the opening of the Lick Observatory kind friends have provided ways and means for the despatching of expeditions to observe all the observable total solar eclipses, except that of last January which was visible in Turkestan and for which the weather-conditions seemed likely to be so unfavorable that it was not worth while preparing for it. There have been ten expeditions in all, providing for the observations of eight eclipses. All have been successful except the Japanese and the Labrador expeditions, for which the sky was totally obscured by clouds. The greatest value of the many successful observations secured lies in the continuity of the series.

As is well known, a total eclipse will occur on January 3, 1908, visible in the central Pacific Ocean. The shadow-path crosses but two known portions of land, Flint and Hull Islands. The conditions are much more favorable at the former, the eclipse occurring at about 11.18 a.m., local mean time, with the sun at an altitude of 75°, and the duration of totality being approximately four minutes. Flint Island is in longitude west 151° 48′ and latitude south 11° 26′, and is 389 geographical miles N.N.W. of Papeete, Island of Tahiti. While the weather conditions at that time of the year are not especially favorable, yet the great altitude of the Sun, the long duration of totality, and the desire to give continuity to the observations, and if possible to bring certain lines of investigation to a close, led Direc-

tor Campbell to plan for the sending of an expedition to observe the phenomenon. He was fortunate in enlisting again the interest of Wm. H. Crocker, Esq., of San Francisco, who defrayed the expenses of five previous expeditions.

The problem of transport to and from Flint Island of the observers, apparatus and supplies was unusually difficult. No steamers sail regularly to the island, and it was not found possible to arrange for a steamer passing within a few hundred miles of the island to divert its course in order to land and re-embark the expedition. The matter was brought to the attention of the Navy Department of the U.S. Government, and they most generously undertook to meet Director Campbell's requirements, by providing a war vessel to transport the expedition from Tahiti to Flint Island and return. The ship assigned to this duty is the gun-boat *Annapolis*. It will be under the personal command of His Excellency Governor Moore, U.S.N., of the Island of Tuituila, Samoa. The accommodation on board the *Annapolis* is limited, and the number on the expedition must not exceed twelve.

It seemed very desirable to Director Campbell that a bolometric survey of the corona should be undertaken on this occasion, in continuation of Professor Abbot's observations at the eclipse of 1900. As Professor Abbot is the astronomer best fitted to undertake this work the Director suggested to Secretary Walcott, of the Smithsonian Institution, and to Professor Abbot, that they send an expedition for this purpose, the two expeditions to be independent scientifically, but travelling and subsisting together. The Secretary has most fortunately arranged for this expedition, which will consist of Professor Abbot and one assistant. It is expected that Messrs. Campbell, Aitken, Perrine and Albrecht, of the Lick Observatory staff; Professor Lewis, of the Department of Physics, University of California; Professor Abbot and his assistant; and one or two assistants not yet definitely determined upon will sail from San Francisco on November 22 for Tahiti, at which place they will probably arrive on December 4. The *Annapolis* will at once convey the

party to Flint Island. The expedition should re-embark about January 5 for Tahiti, and leave the latter port on January 13 for San Francisco. One or two mechanics and servants and one or two workmen will be secured either at San Francisco or Tahiti.

The coronal photographs with the camera of 40 feet focus pointed directly at the Sun will be continued. Likewise the photographs with a camera of aperture 5 inches and focal length 70 inches. The large-scale records will necessarily be of especial interest for studying the structure of the inner corona, and those on a smaller scale for that of the outer corona. There will be two groups of cameras—four in each group—for photographing the region east and west of the Sun, along the line of the Sun's equator, for the purpose of recording the presence of any bodies such as intra-Mercurial planets which may exist there. Dr. Perrine's work in Sumatra in 1901 and in Spain in 1905, though hindered by light clouds in both cases, has made it probable that no intra-Mercurial planets of considerable size exist. Stars were recorded down to the 8th magnitude in substantially the entire region searched. If planets fainter than the 7th or 8th magnitude exist there would have to be an enormous number of them to provide sufficient mass to account for the anomalies in the motions of Mercury's perihelion. Consequently any small bodies that may be discovered near the Sun would be interesting on their own account rather than in connection with the motion of Mercury. The cameras are capable of recording 9th and 10th magnitude stars with an exposure of three or four minutes, and it is hoped that favorable conditions on Flint Island may enable the record to be carried to this limit. The recent mathematical researches of Professor Seeliger, apparently showing that the material responsible for the Zodiacal Light exists in sufficient quantities to explain the anomalies in Mercury's motion, together with the photographs obtained by previous expeditions from the observatory, practically have brought the famous intra-Mercurial problem to a close.

Objective-prism spectrographs will be used to record the spectrum of the Sun's edge, near the instants of beginning and

ending of totality. One of these will have exposures on a fixed plate to record the uneclipsed crescents of the Sun's atmosphere. The other will make the exposure on a continuously moving plate, in order to record the changing spectrum of the Sun's edge as the edge is gradually covered at contact *two* and uncovered at contact *three*. The advantage of the moving plate is that it gives a continuous record of the changes which occur, whereas the fixed plate gives an integrated effect for a short interval, while what the spectrum was before and after exposure is unknown. The method was applied by Director Campbell at the eclipses of 1898, 1900 and 1905, and the records obtained show in the most beautiful manner how the dark lines change to bright ones and at what depths in the Sun's atmosphere they begin and end. Indeed one can hardly conceive a more striking method of exploration. In this connection I may say that the study of the eclipse photographs of 1905 is proceeding satisfactorily, and it is hoped that all the results will be published in the near future.

There will be a low-dispersion spectrograph for recording the general structure of the corona. The coronal spectrograms obtained in Sumatra and Spain, showing the ordinary Fraunhofer solar type of spectrum for the outer corona, were taken through thin clouds, and it is hoped to eliminate the possible effect of clouds in modifying the apparent type of the spectrum. There will be another spectrograph for the determination of the wave-length of the green coronal line, and still another for studying the form of the incandescent gaseous stratum responsible for that green line.

The polarigraphs used by Dr. Perrine in Spain will be taken to Flint Island. The study of the brightness of the corona as a whole will also be undertaken. Professor Lewis has a large quartz spectrograph, with which he will attempt to record the ultra-violet spectrum of the corona. The expedition will be supplied with auxiliary instruments for determining the time, and latitude and longitude for the adjustment of the spectrographic apparatus.

Flint Island is approximately half-a-mile wide and 2½ miles long. Its surface is about 14 feet above the sea level. The population consists of an English foreman and twenty or thirty natives, all of whom are engaged in the copra industry.

OBSERVATION OF DOUBLE STARS; CORRECTION TO MR. ESPIN'S NOTE.

In April 1899 Professors R. G. Aitken and W. J. Hussey began a systematic search for new pairs of double stars in that portion of the sky north of declination – 22°. During 1899 comparatively little was done, but since then no occasion has been lost in pushing the search. Professor Hussey withdrew from the work on his leaving the observatory in 1905, and since then Professor Aitken has continued the work alone. The great refractor is used on four nights each week for spectrographic work, on Saturday until 10 p.m. for visitors—who come in great numbers—and the other time is devoted to double star observations. In the great catalogue of double stars prepared by Burnham and very recently issued, Burnham gives a list of 1336 discovered by himself. Counting 137 stars just announced in Lick Observatory *Bulletin* No. 117, Hussey's discoveries amount to 1337. Of these, however, 10 are of southern doubles and have not been properly measured. Professor Aitken has already published more than 1500 new pairs, and has over 100 more ready to publish, and thus he now is decidedly in the lead in this work. His great survey will likely be completed in two years.

Besides this work the measurement of binaries has been kept up-to-date, and Dr. Aitken's card catalogue of these objects is a veritable mine of interesting information.

On account of the great resolving power of the 36-inch telescope—and the keen eye of the observer—many interesting extensions of the labors of other observers have been made. The writer has been given some interesting examples. The star 29 *Hydræ* was pronounced double by Burnham 20 years ago. It is now found that the principal component, of 6·5 magnitude,

is itself a close double; and since all the components have the same proper motion, one can conclude that they form a physical system. Star number 75 in Espin's list in *A.N.* 3784, with R.A. $15^h\ 15^m{\cdot}9$, declination + 46° 29′ (1880) is given by its discoverer as double. It is found to be triple. Star β 370 = *B. D.* + 52°·2963 in Burnham's list is given as a binary, being an eighth magnitude star with a ninth magnitude companion. It is now found to be quadruple.

Professor Aitkin informs me that there is a mistake in Rev. T. E. Espin's "Notes on Double Stars" in the last number of the JOURNAL, and I cannot do better than give here a note of correction prepared by Dr. Aitken:

"The Rev. Mr. Espin is usually correct in his statements relating to double stars, but he is mistaken in thinking that the pair *B. D.* + 29°.1821, near *t Cancri* is new. It was discovered by me on February 20, 1903, and is included as A 553 in the list printed in the Lick Observatory *Bulletin* No. 50. Possibly a mistake in bringing forward the star place accounts for the failure to recognize the identity of the two pairs, for the correct position for 1900 is R. A. $8^h\ 39^m\ 53^s$, decl. + 29° 22′.

"My measures give

1903.16 70°·4 2″·44, 3 nights, 36-inch.

There is no other similar pair in the vicinity."

Beside the work on double stars, micrometric measurements on the comets and satellites too faint for the 12-inch telescope are regularly made with the 36-inch. At present the satellites of Mars and Uranus are being observed, and Kopff's comet 1906 *b* = 1905 IV has been followed from April 20 to July 3. At the last observation the object was so faint—about the sixteenth magnitude—that when the absence of the Moon allows another observation to be made it will probably be invisible.

THE MERIDIAN CIRCLE.

The meridian circle belonging to the observatory has an aperture of 6·4 inches, and is one of the fine productions of the Repsolds. It was mounted twenty years ago, and for three quarters of that period has been in active use. It is in charge of Professor R. H. Tucker, who, before joining the observatory staff in 1893, had had much experience in meridian circle work

at the Dudley Observatory, Albany, N. Y., and the Cordoba Observatory in the Argentine Republic. A skilful observer may secure good results with an inferior instrument, but the best results can only be obtained with a first class instrument in the hands of an experienced and able observer. This instrument has been investigated in great detail, and the final test, that given by the results obtained in its use, has shown that it is of the highest mechanical design and construction.

There are certain classes of errors that remain constant for one instrument, and the investigation of these can be expected to give data which will be useful for a long period of time, and for the various observers who may use the instrument. The flexure and the division error are included in this class. These have been extensively investigated for the meridian circle. The first is of very small size, certainly less than ·10″. The measurement of every division of the graduated circles is a labor too great for any single observer if all his time for a term of years were to be devoted to that alone. The fixed circle of this instrument has been measured completely down to the 10′ divisions; the movable circle down to 3°. Also large numbers of the 2′ divisions have been measured, so that corrections can be applied, either directly for the divisions used, or by interpolation for intermediate divisions. Other classes of instrumental errors are constantly determined, as well as the errors of the investigator, the result perhaps of personal peculiarity in the first place and confirmed by long habit eventually.

The instrument is now being used for work of a fundamental character, in which the greatest refinement of methods is necessary. Few observatories undertake this line of work, but about once in a generation the need becomes somewhat pressing for a revision and adjustment of our fundamental system of star places.

Two volumes of meridian circle measurements have been issued and a third volume is now going through the press. The first volume contains observations of standard stars mainly. The

second includes a long list of southern stars, and the stars for Eros which were observed at many other observatories. The present volume, in addition to miscellaneous lists, contains the stars of the Zodiacal Catalogue, which are also to be observed elsewhere. In all about 25,000 observations of star places have been completed and prepared for publication.

The work of this department has naturally included the rating of the fine clocks, of which the observatory has six, including a new Riefler, enclosed in air-tight glass case and wound electrically.

The work at the present time will be a contribution to the knowledge of the positions of the standard stars, just as previous work has contributed to that of the greater mass of less prominent stars. It is hoped to round out consistently a programme that has included a number of detached and a number of closely related schemes.

THE KEELER MEMORIAL VOLUME.

James Edward Keeler was appointed director of the observatory in June 1898, and died in August 1900. In the short interval his work with the Crossley Reflector was such a distinguished success that it produced a decided revival in the use of such instruments.

For some time a Memorial Volume has been in preparation, the work being in charge of Professor Perrine, who took over the reflector at the decease of the late director, and completed his programme, of which all but one third had been carried out. The volume, which will be one of the regular publications of the observatory, will contain seventy illustrations, representing the most interesting nebulæ and clusters within reach of the instrument at its present latitude. Great difficulty has been experienced in securing proper reproduction of the original negatives, as it is desired to show not only the detail of the denser portions but the fainter parts as well. One fourth of the engraving has been done and the rest will be secured as soon as possible.

The volume will also contain a brief memoir, a reprint of Keeler's well-known paper on the Crossley Reflector and a catalogue of new nebulæ discovered on the negatives. On the 103 plates taken 744 new nebulæ were found. Each of these plates covers three-fourths of a square degree and as they were well distributed throughout the sky a simple calculation leads to the conclusion that over 500,000 nebulæ are within the reach of the Reflector with an exposure of four hours.

Paper photographs, no matter how carefully made, are not suitable for original research, which should be made with glass plates. It is hoped that means will be found to prepare six or eight sets of glass positives of these Crossley photographs of nebulæ and star clusters, to be deposited, for the use of investigators, with leading learned societies and institutions throughout the world.

Reference has been made above to alterations made in the optical system of the Reflector. Its mounting was entirely remodelled, according to Dr. Perrine's plans, in 1903. In 1904 Saturn's ninth satellite was photographed and soon after this followed the discovery of Jupiter's sixth and seventh moons.

For some time Dr. Perrine has been investigating the distortions of photographic films, preparatory to undertaking his parallax programme. The discordance between successive photographic plates of an object is many times greater than the errors of measurement. Much of the trouble lies in the structure of the photographic film. If the difficulty can be overcome a great advance in the means of research will be attained.

The above notes, though somewhat extensive, by no means exhaust the activities of the Lick Observatory. Systematic studies of the different classes of variable stars are in progress, an important contribution to this subject by Dr. Albrecht having recently appeared. An investigation is also being made into the Zodiacal Light; while no new object appears in the heavens—such as a *nova* or a comet—without being promptly attacked. In cases of emergency the entire resources of the observatory are turned to the study of a new phenomenon.

Another matter which strongly impresses the visitor is that the doors of the observatory are never closed, and at almost any hour of the day or night someone can be found busy in observation or investigation. Indeed the energy, enthusiasm and earnestness of purpose of the Director are reflected throughout the entire institution; and the spirit of investigation seems to saturate the rare air about the summit of the mountain.

LICK OBSERVATORY,
MT. HAMILTON,
JULY 20, 1907.

NOTES FROM THE DOMINION OBSERVATORY.

Astrophysics.—The new spectrograph is performing very satisfactorily and is gradually being brought into the condition and adjustment to give the greatest possible accuracy in radial velocity determinations. It has been used mostly with the single prism on first type stars with broad Hydrogen lines. Owing to the very satisfactory field of the camera lens accurate measures can be obtained of $H\beta$ and $H\delta$ and, when the spectra are sufficiently exposed, of $H\varepsilon$ as well as $H\gamma$, which was the only H line formerly measurable.

There are now seven spectroscopic binaries under regular observaton, and the measurements on some of these are fairly well up to date. Besides α *Draconis*, whose orbit is given in another part of this issue by Mr. Harper, and ι *Orionis*, mentioned in the last notes, considerable progress has been made on the velocity curves of four of these, and it is hoped that their provisional elements may soon be published. A new method, modified from that by Hartmann, has been applied to the reduction of star spectra. The necessary work is thereby much simplified, rendered less laborious and tedious, and the liability to numerical mistakes lessened. A considerable saving of time is also effected while equally accurate determinations are obtained. This is proved by reductions by the two methods from the same measurements, the differences in the resulting values being only two or three tenths of a kilometer, which has no significance in single prism work with early type stars. The method has not yet been applied to the three prism plates as, waiting the production of a flat field objective, not many spectra have yet been obtained. Numerous experiments looking to the improvement of the existing field in spectrograph camera objectives are being carried on and it is hoped to obtain a field of 8° instead of the 2° or 3° at present available.

Word has just been received from the Brashear Co. that the new correcting lens, computed by Dr. C. S. Hastings, has been completed and shipped. They are hopeful that it will be a considerable improvement over the original corrector whose aberrations were recently investigated by me. I hope in the next issue of the JOURNAL to give an account of this investigation, as well as of the tests of the new lens.

We are also much indebted to Dr. Brashear for supplying a 6-inch plane grating of the first quality, ruled by Michelson, for use with the cœlostat telescope in solar research.

Daniel's comet, which has rapidly been increasing in brightness and at the date of this writing is of about the fourth magnitude, was photographed by the 8-inch Brashear doublet on July 20. A very good photograph was obtained showing much detail in the tail, which is divided into five or six streamers and is of quite a complex structure. The longest streamer, extending upwards of 6°, divides into two at a distance of about 2° from the nucleus. It is proposed to obtain photographs as frequently as possible while the comet is increasing in brightness.

The staff in astrophysics has been materially strengthened by the appointment and arrival of Ralph E. de Lury, Ph.D., R. M. Motherwell, B.A., and J. N. Tribble, B.A. Dr. de Lury, whose training in physical chemistry will prove of much service to him in his new duties, will undertake work in solar research with the new cœlostat telescope to be shortly installed; Mr. Motherwell will have the micrometer observations with the equatorial, and Mr. Tribble will engage in radial velocity work.

J. S. P.

The Seismograph.—Since the last notes were written the principal earthquakes recorded by the seismograph were:

June 1. Preliminary tremors $3^h\ 48^m\ 45^s$ A.M., for the E–W pendulum, *i.e.*, for the one moving N–S, while for the other pendulum at right angles to the former, the time was $3^h\ 55^m\ 14^s$. As the epicentre was found to have been in Ecuador, which is due south of Ottawa, it would appear that the first longitudinal

waves, after all the supposed reflections and refractions by the different media of the earth, reached the seismograph in a direction due north and south, thereby leaving the pendulum, whose mounting is N–S, practically unaffected, *i. e.*, "hitting it head-on," having the maximum effect on the E–W pendulum.

The next considerable quake occurred on June 13, when the preliminary tremors arrived at $4^h\ 30^m\ 46^s$ A.M., and the principal portion at $4^h\ 41^m\ 00^s$. The quake lasted about 50 minutes. For that same morning telegraphic despatches from Kingston, Jamaica, reported "a violent earthquake," destroying at Port Royal the walls of the temporary buildings under construction; and from Valdivia, in Chile, the report speaks of a "severe earthquake" destroying several buildings, and railroad bridges, also killing five persons. Letters since then have been received from the headwaters of the Copper river in Alaska, where a decided earthquake was felt by prospectors on that same morning. As Valdivia is in latitude 39° 53′ south, and 73° 25′ west longitude, while for the place in Alaska we may take 63° and 145°, it follows that a more or less severe seismic disturbance took place apparently about simultaneously at points over 8,000 miles apart, together with an intermediate one at Jamaica. What relationship, if any, exists between the three phenomena it is impossible at present to say. Perhaps later, with accurate time data, not now available, a connection may be established. The last of the important disturbances recorded was of July 1st, when the preliminary tremors arrived at $8^h\ 15^m\ 48^s$ A.M., and the principal portion at $8^h\ 21^m\ 14^s$. Judging from the amplitude of the movement of the pendulum the quake was more severe than the destructive one of January last at Kingston. As the Washington seismograph recorded the quake 55 seconds earlier, it is evident that the direction of the preliminary wave came practically due north. The epicentre of this earthquake is at the time of writing not known to the writer.

The founding of a Department of Research in Terrestrial Magnetism in connection with the Carnegie Institution at Washington has given a decided impetus to that important branch of

science, and before many years the continent of North America will have the magnetic elements determined and reduced to a uniform epoch for the greater part of its area. During the past year many stations have been occupied from Halifax westward as far as Regina. At present an officer of the Dominion Observatory is supplementing stations in Ontario, using a Tesdorpf magnetic instrument for declination, inclination, and horizontal intensity. The first systematic magnetic survey of Canada instituted by Sir Edward Sabine, was made by Lieutenant Lefroy (later General Sir J. H. Lefroy) in 1843–44. Toronto was then, as it is to-day, the most important magnetic station on the continent, and to it all of Lefroy's observations were referred.

It is intended to re-occupy some of Lefroy's stations for the purpose of determining secular variation. For this purpose it is very essential, in areas where local attractions may be suspected, that the precise spot be re-occupied, otherwise the results may be misleading.

O. K.

AN APPEAL FROM THE ASTRONOMICAL SOCIETY OF THE PACIFIC.

THE library of the Astronomical Society of the Pacific, containing 1350 bound volumes, nearly as many unbound volumes and pamphlets, and a valuable collection of photographs, which had been acquired by judicious purchases and generous donations during the seventeen years of the Society's existence, was destroyed by the great San Francisco fire of April, 1906.

The funds realized from the insurance are sufficient to restore only a small portion of the Society's loss, and the Board of Directors have decided to appeal to the members of the Society, the subscribing libraries, the corresponding institutions, and other friends for help in building up a new library, for it is only through generous contributions from these sources that the Society can hope to replace the many valuable series of publications of observatories, transactions of societies, and astronomical periodicals which our former library contained.

Peculiarly favorable meteorological conditions promise to make the western coast of the United States a great centre for astronomical research. Two of the world's greatest research observatories already established are a recognition of this fact and a guarantee for the future of astronomical research on the Pacific Coast. This, with the rapid material development of the section and its increasing population, opens to the Astronomical Society of the Pacific a prospect for a career of great usefulness in the work of mediation between the world of astronomical research and humanity at large. In this work a good library is indispensable, and any contributions of astronomical works that the friends of the Society may see fit to offer will be very gratefully received.

Permanent rooms for the Society have not yet been obtained, but temporary quarters have been provided by the University of California, and all contributions to the library and communications concerning it should be addressed, Astronomical Society of the Pacific, Students' Observatory, Berkeley, California, U. S. A.

CHARLES H. CUSHING, President.

R. T. CRAWFORD, Secretary.

ASTRONOMICAL NOTES.

A number of planetary observers have noted at times a want of uniform motion in the shadows of a satellite passing across Jupiter's disc. This is pointed out by Mr. H. P. Hollis in *Journal British Astronomical Association* for June, page 360, as a necessary result of the shadow passing over a spherical surface.

In the same number Gavin J. Burns considers the efficiency of dust in space as a light absorbent, and concludes it improbable that the light coming to us from the stars is sensibly diminished by absorption from such a cause in inter-stellar space. Absorption by the etherial medium, on the other hand, is considered as not being a legitimate scientific hypothesis, as our present physical knowledge lends no support whatever to such an assumption.

The June number of *The Observatory* contains a note from W. F. Denning, in which he says:

With Saturn becoming more favourably visible in the morning sky, it is hoped observers will examine the planet for traces of spots and irregularities in the belts. The present time offers good opportunities for detecting any equatorial white spots that may be visible. It is important to determine the rotation period from further markings, the value found by Herschel from a quintuple belt in the southern hemisphere (in 1793–4) being $10^h\ 16^m\ 0^s{\cdot}44$, by Prof. Hall from an equatorial white spot (in 1876-7) $10^h\ 14^m\ 23^s{\cdot}8$, and by the writer from a number of white and dark spots in N. temp. region (in 1903, July–December) $10^h\ 37^m\ 55^s{\cdot}2$. The value derived in 1903 exhibits a difference of more than 20 minutes as compared with the earlier determinations.

The disturbances visible in 1903 in the northern hemisphere appear to have been on a larger and more abundant scale than had ever previously been recognized. Since the year named there have been but slender and occasional evidences of irregularities in the dark belts or bright zones, but a few spots were seen in 1905 and 1906 in similar positions to those of 1903.

EPHEMERIS OF DANIEL'S COMET.

August 23,	R. A.	$7^h\ 49^m\ 30^s$	Dec.	$+15°\ 51'$,
" 25,	"	$8^h\ 4^m\ 30^s$	"	$+15°\ 17'$,
" 27,	"	$8^h\ 18^m\ 49^s$	"	$+14°\ 45'$.

SUMMARY REPORT OF THE WEATHER IN CANADA. JUNE, 1907.

Temperature.—The mean temperature was a little higher than average in the northern portions of Ontario, Manitoba and Saskatchewan and on Vancouver Island, while in other parts of the Dominion it was below average, the largest negative departure, about 4°, being in Southwestern Ontario. The month opened rather cool in nearly all parts of the Dominion, but within a few days the weather became warm and seasonable. In the West no very pronounced heat spells have occurred, but in Ontario and Quebec since the 16th the temperature has frequently exceeded 80°, and on several days 90° has been reached in many localities.

The following are the highest and lowest temperatures recorded at various stations :—

British Columbia.—Dawson, 86, 31 ; Atlin, 70, 32 ; Port Simpson, 66, 40 ; Victoria, 78, 43 ; New Westminster, 82, 40 ; Barkerville, 84, 34 ; Kamloops, 94, 43 ; Agassiz, 87, 38 ; Chilliwack, 85, 40.

Western Provinces.—Edmonton, 84, 35 ; Battleford, 88, 34 ; Prince Albert, 82, 32 ; Calgary, 80, 33 ; Medicine Hat, 86, 35 ; Swift Current, 84, 33 ; Qu'Appelle, 82, 34 ; Minnedosa, 80, 30 ; Winnipeg, 88, 32 ; Portage la Prairie, 87, 38.

Ontario.—Port Arthur, 86, 34 ; White River, 85, 30 ; Southampton, 89, 35 ; Parry Sound, 91, 40 ; Port Stanley, 80, 38 ; Toronto, 87, 44 ; Kingston, 82, 43 ; Rockcliffe, 94, 35 ; Ottawa, 94, 45 ; Sutton West, 91, 40 ; Paris, 89, 40 ; Haliburton, 91, 32 ; Bruce Mines, 90, 38 ; Port Dover, 82, 40 ; Welland, 90, 45 ; Peterboro', 89, 38 ; Huntsville, 85, 41 ; Kenora, 89, 37 ; Owen Sound, 92, 36 ; Uxbridge, 90, 40 ; Port Burwell, 81, 41 ; Bloomfield, 87, 41 ; Bancroft, 92, 33 ; Otonabee, 87, 44 ; Beatrice, 87, 35 ; Stony Creek, 92, 37 ; Stratford, 89, 39 ; Brantford, 88, 39 ;

Agincourt, 89, 40; Barrie, 91, 42; Hamilton, 92, 44; Clinton, 89, 35; Lake Talon, 90, 35.

Quebec.—Montreal, 87, 44; Quebec, 89, 40; Father Point, 75, 33; Sherbrooke, 91, 36; Ste. Anne de Bellevue, 92, 43.

Maritime Provinces.—Charlottetown, 75, 35; Chatham, 94, 34; Sydney, 82, 28; Halifax, 84, 37; Yarmouth, 74, 33; St. John, 76, 38; Fredericton, 91, 34; Sussex, 85, 26; Moncton, 90, 30; Dalhousie, 84, 42; Pt. Lepreaux, 67, 40; Windsor, 87, 33.

PRECIPITATION.—Over the Dominion as a whole the rainfall of June was less than average, the most pronounced deficiencies occurring in Southern New Brunswick, New Ontario and in British Columbia. In Alberta the fall was nearly average, as it also was in Northern New Brunswick and Southwestern Ontario. Nearly all stations in the Province of Quebec recorded an excess approximating one inch; and Western Manitoba and Southern Saskatchewan also recorded an excess, and in some few localities the rainfall may have been as much as double the average amount.

JULY, 1907.

TEMPERATURE.—A supernormal mean temperature was recorded in July over Vancouver Island and the Cariboo District of British Columbia; also very locally in Alberta, Saskatchewan, Ontario, and Southwestern Quebec, but over the greater portion of Canada the mean temperature was subnormal. Departures from average were not pronounced, except locally in Southwestern Saskatchewan, where a negative departure of five degrees was recorded at Swift Current.

The following are the highest and lowest temperatures recorded at the various stations:—

Yukon Territory.—Dawson City, 84, 36.

British Columbia.—Atlin, 80, 36; Port Simpson, 74, 46; Victoria, 88, 47; Vancouver, 90, 44; New Westminster, 92, 44; Agassiz, 97, 42; Kamloops, 98, 46; Barkerville, 82, 36.

Western Provinces.—Calgary, 84, 40; Edmonton, 81, 44; Medicine Hat, 92, 45; Battleford, 82, 44; Prince Albert, 80, 41;

Swift Current, 86, 38; Regina, 82, 40; Minnedosa, 88, 40; Portage la Prairie, 86, 43; Carman, 87, 44; Winnipeg, 87, 40.

Ontario.—Kenora, 85, 45; Port Arthur, 84, 40; White River, 80, 36; Bruce Mines, 84, 39; Cockburn Island, 82, 42; Copper Cliff, 86, 41; Parry Sound, 92, 40; Huntsville, 84, 46; Beatrice, 84, 40; Owen Sound, 90, 40; Southampton 86, 39; Meaford, 84, 44; Lucknow, 90, 32; Clinton, 86, 34; Sarnia, 84, 40; Port Stanley, 92, 40; Port Dover, 85, 41; Stratford, 86, 39; Port Burwell, 82, 41; Brantford, 89, 38; Paris, 87, 42; Uxbridge, 87, 39; Welland 88, 44; Stony Creek, 92, 43; Hamilton, 90, 48; Toronto, 90, 48; East Toronto, 86, 44; Agincourt, 87, 45; Sutton West, 85, 46; Peterboro', 86, 42; Bancroft, 86, 38; Haliburton, 85, 32; Kingston, 84, 47; Rockcliffe, 88, 38; Ottawa, 87, 48.

Quebec.—Montreal, 85, 51; Ste. Anne de Bellevue, 88, 51; Brome, 84, 45; Quebec, 87, 47; Father Point, 74, 44.

Maritime Provinces.—Chatham, 90, 50; St. John, 76, 49; Fredericton, 88, 46; St. Stephen, 90, 44; Moncton, 87, 47; Sussex, 86, 47; Yarmouth, 72, 47; Halifax, 87, 49; Sydney, 83, 41; Charlottetown, 83, 51.

PRECIPITATION.—Precipitation in July was deficient over a considerable portion of Canada, but an excess was recorded over large sections of Manitoba, New Ontario, Quebec, and the Maritime Provinces. Vancouver Island, in British Columbia, also recorded an amount slightly in excess of the average. Departures from normal were very marked, positive differences being as high as 95 per cent. in the Gaspé Peninsula of Quebec and Northern New Brunswick, and negative departures of from 55 per cent. to 64 per cent. were recorded in the southern portions of Alberta and Saskatchewan.

METEOROLOGICAL OFFICE,
TORONTO,
AUGUST 5th, 1907.

Swift Current, 86, 38; Regina, 82, 40; Minnedosa, 88, 40; Portage la Prairie, 86, 43; Carman, 87, 44; Winnipeg, 87, 40.

Ontario.—Kenora, 85, 45; Port Arthur, 84, 40; White River, 80, 36; Bruce Mines, 84, 39; Cockburn Island, 82, 42; Copper Cliff, 86, 41; Parry Sound, 92, 40; Huntsville, 84, 46; Beatrice, 84, 40; Owen Sound, 90, 40; Southampton 86, 39; Meaford, 84, 44; Lucknow, 90, 32; Clinton, 86, 34; Sarnia, 84, 40; Port Stanley, 92, 40; Port Dover, 85, 41; Stratford, 86, 39; Port Burwell, 82, 41; Brantford, 89, 38; Paris, 87, 42; Uxbridge, 87, 39; Welland 88, 44; Stony Creek, 92, 43; Hamilton, 90, 48; Toronto, 90, 48; East Toronto, 86, 44; Agincourt, 87, 45; Sutton West, 85, 46; Peterboro', 86, 42; Bancroft, 86, 38; Haliburton, 85, 32; Kingston, 84, 47; Rockcliffe, 88, 38; Ottawa, 87, 48.

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